REPORT OF THE

DEFENSE SCIENCE BOARD

TASK FORCE

ON

CONCURRENCY AND RISK OF THE F-22 PROGRAM

APRIL 1995

OFFICE OF THE UNDER SECRETARY OF DEFENSE
FOR ACQUISITION & TECHNOLOGY
WASHINGTON, D.C. 20301-3140

This report is a product of the Defense Science Board (DSB). The DSB is a Federal Advisory Committee established to provide independent advice to the Secretary of Defense. Statements, opinions, conclusions and recommendations in this report do not necessarily represent the official position of the Department of Defense.

This document is UNCLASSIFIED.

Security review completed 28 March 1995 by OASD (Public Affairs) directorate for Freedom of Information and Security Review Case number 95-C- 0705.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188
Exp. Date: Jun 30, 1986

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS N/A
2a. SECURITY CLASSIFICATION AUTHORITY N/A	3. DISTRIBUTION/AVAILABILITY OF REPORT Distribution Statement A. Approved for Public Release: Distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) N/A	5. MONITORING ORGANIZATION REPORT NUMBER(S) N/A
6a. NAME OF PERFORMING ORGANIZATION Defense Science Board, Ofc of the Under Secy of Def (A&T) 6b. OFFICE SYMBOL (If applicable) DSB/OUSD(A&T)	7a. NAME OF MONITORING ORGANIZATION N/A
6c. ADDRESS (City, State, and ZIP Code) The Pentagon, Room 3D865 Washington, DC 20301-3140	7b. ADDRESS (City, State, and ZIP Code) N/A
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Defense Science Board, OUSD(A&T) 8b. OFFICE SYMBOL (If applicable) DSB/OUSD(A&T)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N/A
8c. ADDRESS (City, State, and ZIP Code) The Pentagon, Room 3D865 Washington, DC 20301-3140	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO.: N/A PROJECT NO.: N/A TASK NO.: N/A WORK UNIT ACCESSION NO.: N/A

11. TITLE (Include Security Classification) Report of the Defense Science Board Task Force on Concurrency and Risk of the F-22 Program, Unclassified.

12. PERSONAL AUTHOR(S)
N/A

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM N/A TO N/A	1995 April	55

16. SUPPLEMENTARY NOTATION
N/A

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

DTIC QUALITY INSPECTED 5

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION
22a. NAME OF RESPONSIBLE INDIVIDUAL Diane L.H. Evans	22b. TELEPHONE (Include Area Code) (703) 695-4157/8 22c. OFFICE SYMBOL DSB/OUSD(A&T)

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

OFFICE OF THE SECRETARY OF DEFENSE
WASHINGTON, D.C. 20301-3140

DEFENSE SCIENCE
BOARD

17 APR 1995

MEMORANDUM FOR UNDER SECRETARY OF DEFENSE (ACQUISITION & TECHNOLOGY)

SUBJECT: Report of the Defense Science Board (DSB) Task Force on Concurrency and Risk of the F-22 Program

I am pleased to forward the final report of the DSB study on the F-22 program. This study was conducted at your request to assess the degree of concurrency and risk in the F-22 program as directed by the Senate Armed Services Committee in the SASC Report 163-282, dated 14 June 1994.

The F-22 is the next generation air superiority fighter with many "first time" features (super cruise, vectored thrust, stealth, passive location systems, integrated avionics) making it one of the most challenging developments undertaken. The overall program has been structured to address all these areas in an orderly and appropriate way.

The Task Force concluded that the critical point in the program is the ramp-up in the production from 4 aircraft to 12 aircraft per year. This is also the time the engine and the passive surveillance avionics subsystem have the greatest number of uncertainties. The Task Force identified for each risk area specific significant events whose accomplishment should take place before contract award for the 12 aircraft buy.

I concur with the recommendations of the Task Force and recommend that you forward the Report to the Secretary of Defense.

Craig I. Fields
Chairman

OFFICE OF THE SECRETARY OF DEFENSE
WASHINGTON, D.C. 20301-3140

DEFENSE SCIENCE BOARD

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Final Report of the Defense Science Board Task Force on Concurrency and Risk of the F-22 Program

I am pleased to forward the final report of the Task Force on Concurrency and Risk of the F-22 Program.

The F-22 is the next generation air superiority fighter scheduled for introduction in the first decade of the next century. The design incorporates major advances in all areas of performance including: stealth, supercruise, vectored thrust, situation awareness and integrated avionics. It is, thus a very ambitious, challenging program, probably the most technically challenging program in recent times.

In response to USD(A&T) tasking, the Task Force examined the concurrency/risk in the F-22 program plan. We found the existing program plan to be detailed, logical and orderly. We reviewed the risks in each major area and identified for each area those key events whose accomplishment was needed to provide assurance that the program was ready to move into significant production rate, from 4 to 12 a/c per year. Further, each of these "events" has a series of preceding accomplishments which given adequate forewarning of potential problems.

We also, as requested, reviewed several studies that compare the F-22 schedule with that of previous fighter programs and concluded that the F-22 plan is consistent with and, in many ways, is more conservative than these other programs.

Our conclusion, thus, is that the F-22 plan has acceptable overlap of development and production (concurrency) and that the risks associated with premature entry into rate production are readily controllable through insistence on meeting the key "events" identified in this report. Thus, there is no reason based upon risk/concurrency considerations to introduce a program stretch at this time. If other reasons cause some program stretch, special attention and support should be given to the engine and the passive location subsystem (a key element of the situation awareness system), the areas with the greatest number of uncertainties at this time.

The Task Force would like to stress one point: there are substantial margins throughout the F-22 specifications and a very capable aircraft would result even if performance fell somewhat short of meeting many or even all of these specs. It is therefore

important that the SPO and OSD not take a rigid stance on meeting all specs but rather, as the program progresses, look at the overall performance, cost and schedule impacts in deciding which if any, performance areas need further work.

The Task Force, given the very short time available, limited its considerations to the "concurrency/risk" issue called for in the Terms of Reference. I would, however, like to offer some personal views regarding this very important and large program.

1. The world's air forces are starting to and will eventually catch up with the F-15/16/18 capabilities. Thus, the US will need to make a "quantum step" improvement in the capability assuming we wish to retain the "overwhelming technological superiority" that served us so well in the Gulf War. We can start on this step now, as the F-22 program is doing, or later. The worst course of action is to invest heavily, then do a major stretch or cancel.

2. The US has invested about $60B on stealth aircraft which has given us a unique and incredibly important military advantage. Our total assets, however, consist of 50 F-117s and 20 B-2s. The F-22 offers the opportunity to expand this advantage substantially.

3. Because of the great complexity and related cost of the system and given its development status, it would be timely to do a careful "scrub" of the subsystems to determine what savings could be accomplished by simplifying, postponing or deleting some items or features (eg., the intra-flight communications system.)

4. Although some steps in the right direction have been taken, the F-22 contract and management approaches do not begin to reflect the acquisition "streamlining" (and resultant cost savings) advanced by the Secretary of Defense. Given that this program will account for a substantial part of the Air Force budget for many years, a major effort in this area is strongly suggested.

The Task Force would like to thank the OSD and IDA staff who ably supported us and to acknowledge their hard work and contributions. Additionally, we want to thank the Air Force and the contractors for their patience and complete cooperation. We could not have done the task without the help of all these people.

Charles A. Fowler

Charles A. Fowler
Chairman

CONTENTS

CHARTS

GLOSSARY

A/C	Aircraft
AFOTEC	Air Force Operational Test and Evaluation Center
AIL	Avionics Integrated Laboratory
BMDO	Ballistic Missile Defense Organization
CA	Contract Award
CDR	Critical Design Review
CIP	Common Integrated Processor
CNI	Communication, Navigation, Identification
COTS	Commercial Off-the-Shelf
DEM/VAL	Demonstration/Validation Phase
DoD	Department of Defense
DSB	Defense Science Board
DT&E	Development Test and Evaluation
EMD	Engineering and Manufacturing Development
ESM	Electronic Support Measures
EW	Electronic Warfare
FBW	Fly-By-Wire
FFR	Full Flight Release
FSD	Full-Scale Development
FTB	Flying Test Bed
GBR	Ground-Based Radar
IFR	Initial Flight Release
IOT&E	Initial Operational Test and Evaluation
IPT	Integrated Product Team
ISR	Initial Service Release
IV&V	Initial Validation and Verification
LL	Long-Lead
LO	Low Observable
LRIP	Low Rate Initial Production
LRU	Line Replaceable Unit
O&S	Operating and Support
OSD	Office of the Secretary of Defense
OT&E	Operational Test and Evaluation
PIO	Pilot-Induced Oscillations
POM	Program Office Memorandum
PPV	Pre-Production Verification
R&D	Research and Development
R&M	Reliability and Maintainability
RCS	Radar Cross Section
SEE	Software Engineering Environment
SFC	Specific Fuel Consumption
SPO	System Program Office
T&E	Test and Evaluation
T/R	Transmit/Receive
TOR	Terms of Reference
USD(A&T)	Under Secretary of Defense (Acquisition and Technology)
UUR	Ultra Reliable Radar

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

INTRODUCTION

PURPOSE

The Defense Science Board Task Force on Concurrency and Risk of the F-22 Program[1] was convened to respond to concerns raised in a Senate Armed Services Report (SASC Report 163-282, dated 14 June 1994.) The Committee requested that the Department of Defense address their concerns related to F-22 Program schedule concurrency. The terms of reference (TOR) for the Task Force from USD(A&T) contain three questions.[2] The questions are:

- Are there are any areas in the F-22 program of excessive concurrency? What is the risk in each area?
- For any areas of identifiable high risk, are viable plans/options available that would mitigate the risk?
- What conclusions regarding F-22 concurrency and risk can be drawn by comparisons to existing data (e.g., an ongoing IDA study) on previous fighter/combat aircraft?

TASK FORCE APPROACH

The Task Force first met on 3 November 1994, briefed its interim findings to DUSD(S&TP) on 7 December and to USD(A&T) on 20 December, and published its interim report on 31 December. During the November-December 1994 time period the Task Force met as a group six times.[3] Briefings and information were received from the Program Office and other sources relevant to answering the questions. A visit was made to the prime contractor, Lockheed Aeronautical Systems Company in Marietta, GA, for further briefings and discussions, and to observe hardware and software demonstrations. Also present at that time were the engine contractor, Pratt & Whitney, and selected major subcontractors. The members, also working as subgroups, made use of other information and available reports.

The Task Force re-ordered the TOR questions in structuring this report, with the last question above on comparing concurrency in the F-22 with other fighter aircraft programs addressed first, the question on areas of concurrency and risk addressed second, and the question on mitigating risk addressed last.

F-22 PROGRAM DESCRIPTION

The F-22 is the next generation air superiority fighter scheduled for introduction in the first decade of the 21st century. Its primary role is to counter emerging proliferating worldwide threats, and to maintain the overwhelming air superiority advantage needed by a downsized and reshaped U.S. military force. The F-22 is designed to penetrate enemy airspace and achieve a first-look, first-kill capability against multiple aircraft targets. The features that will permit the F-22 to achieve this advantage are: a low observable, highly maneuverable airframe making extensive use of composites and low observable materials; advanced software-intensive integrated avionics; improved situational awareness; and a new engine with a two-dimensional vectoring nozzle that is also capable of supersonic cruise without using afterburner.

The advanced nature of the F-22 should be considered in the context of the prior risk reduction effort achieved during an extensive Demonstration and Validation (DEM/VAL) program, which included competitive flying prototypes of the airframe/engine configurations, avionics flying testbeds, and brass board components.

The F-22 has been in Engineering and Manufacturing Development (EMD) since August 1991. First flight is now estimated to be February 1997. The schedule used for the examination of the F-22 Program is the latest provided to the Task Force (Premise Modification to Master Schedule No. 17, dated 16 November 1994).

---

1 The Task Force members are listed in Appendix A.

2 The Terms of Reference are presented in Appendix B.

3 The Task Force schedule is presented in Appendix C.

SUMMARY FINDINGS AND CONCLUSIONS

Findings—Question 1: What conclusions regarding F-22 concurrency and risk can be drawn by comparisons to existing data (e.g., an ongoing IDA study) on previous fighter/combat aircraft programs?

To answer this question it was necessary first to define concurrency and then to compare suitable F-22 concurrency measures to other fighter aircraft programs. In its report to Congress on concurrency in April 1990, DoD defined concurrency and the definition in that report is the definition the Task Force used.

Definition of Concurrency:[4] **Concurrency is the degree of overlap between the development and production processes of an acquisition program. Structuring the overlap is a management judgment balancing risk of proceeding, cost of delay, work force inefficiency, design obsolescence, and operational impact.**

It is important to note that concurrency is the degree of overlap, and degree must be measured in terms of trade-offs and judgments of technical, schedule, and cost risk.

The F-22 was compared to other relevant fighter aircraft programs through examination of studies performed by the Institute for Defense Analyses and RAND Corporation, and through review of other sources of data.[5]

Several F-22 Program Development Test and Evaluation (DT&E) and Initial Operational Test and Evaluation (IOT&E) schedule duration, flight hour activity, and production Lot quantity metrics were compared with the F-15, F-16, and F/A-18 fighter aircraft programs. The Task Force found that the degree of concurrency for the F-22 Program as measured by the data now available is conservative when compared to the other tactical fighters. The key dates are long-lead and contract award for Lot 2 (12 aircraft) by which point key accomplishments will have been demonstrated in all major areas. The Task Force did not think that completion of dedicated IOT&E was necessary before proceeding to production ramp-up.

Findings—Question 2: Are there any areas in the F-22 program of excessive concurrency? What is the risk in each area?

To assess the concurrency of the F-22 program in isolation does not give a complete picture of the potential technical or programmatic risks in the program. Therefore, the Task Force conducted a review of the technical and management status of the program in several key areas. This was done in an effort to relate concurrency and technical risk.

Lot 2 (12 aircraft) Long-Lead and especially Lot 2 Contract Award were considered critical milestones. They were chosen as the critical milestones to balance schedule and cost commitment, while ensuring the fielding of the system in a reasonable time. The two dates span calendar year 1999.

Key decision points were then identified for each of the following critical-technical areas and related to the Lot 2 milestones:

- Airframe—Static and Fatigue Tests Completion; Flight Test (Aircraft 4001)
- Engine—Redesigned Engine Ground Test and First Flight Engine Delivery (Aircraft 4001)
- Low Observables—Pole Model and Flight Testing (Aircraft 4004)
- Radar—Hardware and Software Flight Testing (Aircraft 4005)
- Passive Surveillance and Electronic Warfare—Hardware and Software Flight Testing (Aircraft 4006)
- Sensor Control/Sensor Fusion/Pilot Interface—Hardware and Software Flight Testing (Aircraft 4008)
- Flight Control/Vehicle Management—Early Flight Testing (Aircraft 4001)
- Software—Block 0-1-2-3 Completion Dates

Acquisition key events for the F-22 program are presented in Figure ES-1.

---

4 See Appendix D for citation.

5 See Appendix D for citations.

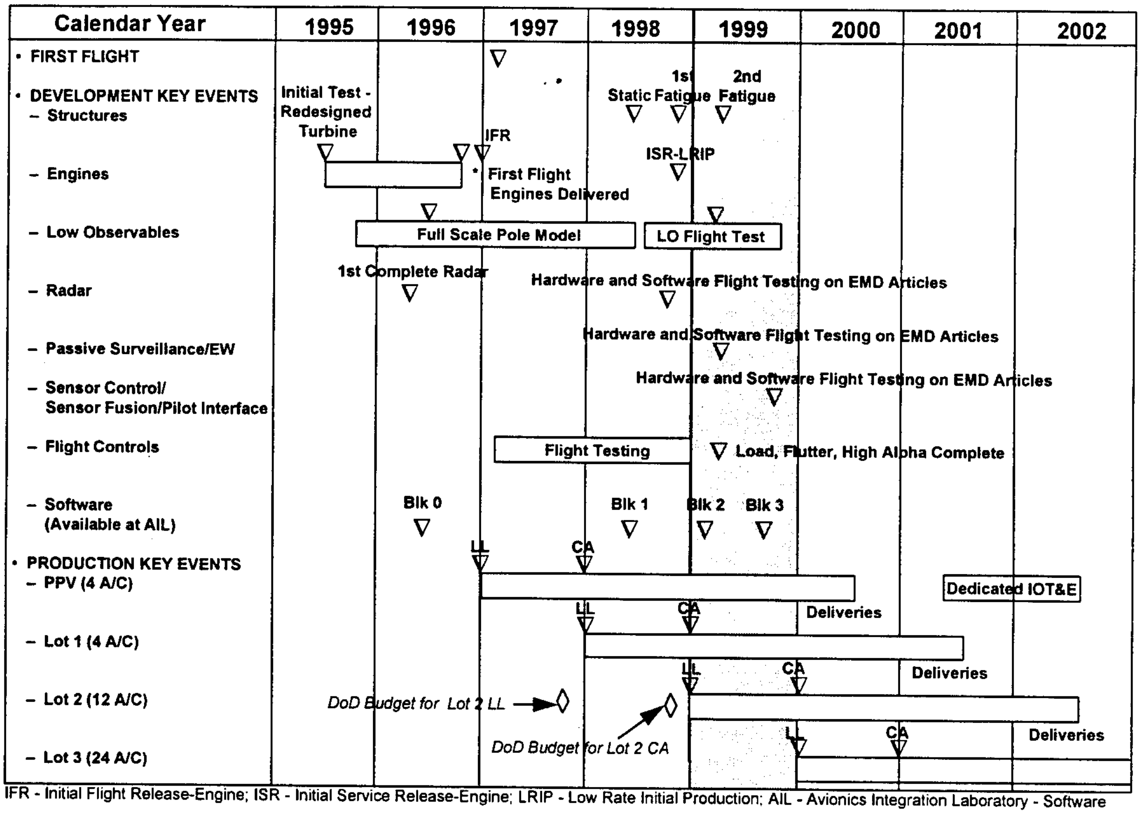


Figure ES-1. F-22 Acquisition Key Events

Findings—Question 3: For any areas of identifiable high risk, are viable plans/options available that would mitigate the risk?

The Task Force addressed the question of viable plans/options available to mitigate high risk areas.

We found that there were no alternative completely independent approaches being pursued for the major subsystems (such as the engine or the radar), and we concluded that such alternative approaches were neither practical nor needed.

There are, of course, alternative approaches being pursued or reviewed at the part/component level (e.g., turbine blades); and others (e.g., LO CNI antennas) can be accommodated within the program's plan and schedule.

We concluded that the best approach to handling problems that do arise is to seriously consider accepting some reduced F-22 performance, slip in the schedule, or some combination of both. As has been noted elsewhere in this report, F-22 overall performance, even if performance fell short of that specified in many subareas, would still represent a major increase in military capability. In the event of significant technical problems, rigid adherence to the current specifications and goals would generally be unproductive and probably very costly.

CONCLUSIONS

With its many "first time" features for a fighter (super cruise, vectored thrust, stealth, passive location system, integrated avionics), the F-22 is one of the most challenging developments undertaken in recent times. The overall program, starting with the prototype in the Demonstration/Validation Phase and related R&D efforts, has been structured to address all these areas in an orderly, appropriate way and much has been accomplished.

From the standpoint of risk/concurrency, the Task Force concluded that the critical point in the program is the ramp-up in the production program from 4 aircraft to 12 aircraft per year (Lot 2).

The Task Force identified, for each major system and subsystem risk area, specific key events whose accomplishment should take place before release of Contract Award (and to a lesser degree Long-Lead) funding for Lot 2, the 12 aircraft buy. (See Figure ES-1).

At this time the engine and the passive surveillance avionics subsystem have the greatest number of uncertainties. Consequently, if there are changes in the program plan, these two areas should receive special attention and continued support.

If there are significant delays in accomplishment of these key events, or if the performance levels achieved are unacceptable, the program could be adjusted by staying at the 4 aircraft per year production rate for an additional year. It is noted that, while stretching a program may reduce risk, if stretching is <u>not</u> necessary it can result in increased total costs, possible loss of key manpower and suppliers, and earlier technical/operational obsolescence.

After careful review of the program plans and accomplishments, the Task Force concluded that there are appropriate future milestones on which to judge readiness for production ramp-up. Thus, there is no reason based upon risk/concurrency to introduce a schedule stretch at this time.

REPORT OF THE DEFENSE SCIENCE BOARD
TASK FORCE ON F-22 PROGRAM
CONCURRENCY AND RISK

TASKING

- What conclusions regarding F-22 concurrency and risk can be drawn by comparisons to previous fighter aircraft programs?
- Are there any areas in the F-22 Program of excessive concurrency? What is the risk in each area?
- For any areas of identifiable high risk, are viable plans/options available that would mitigate the risk?

Terms of Reference: USD (A&T); Nov 1, 1994

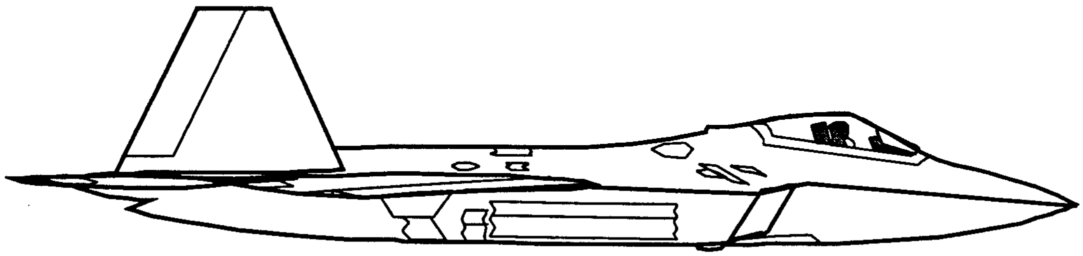
The Task Force reviewed the F-22 Program and its schedule in considerable detail in formulating an approach to the tasking.

The Terms of Reference (see Appendix B) included three tasks as noted above. The first task, reviewing several studies comparing the concurrency in the F-22 program plan with that of other fighter aircraft programs, is covered in pages 5-14.

The second task, reviewing the program and determining and identifying the risk in each major area, is covered in pages 15-33.

The third task, relating to plans/options to mitigate risk in key areas, is covered on page 34.

F-22 KEY FEATURES



Super Cruise

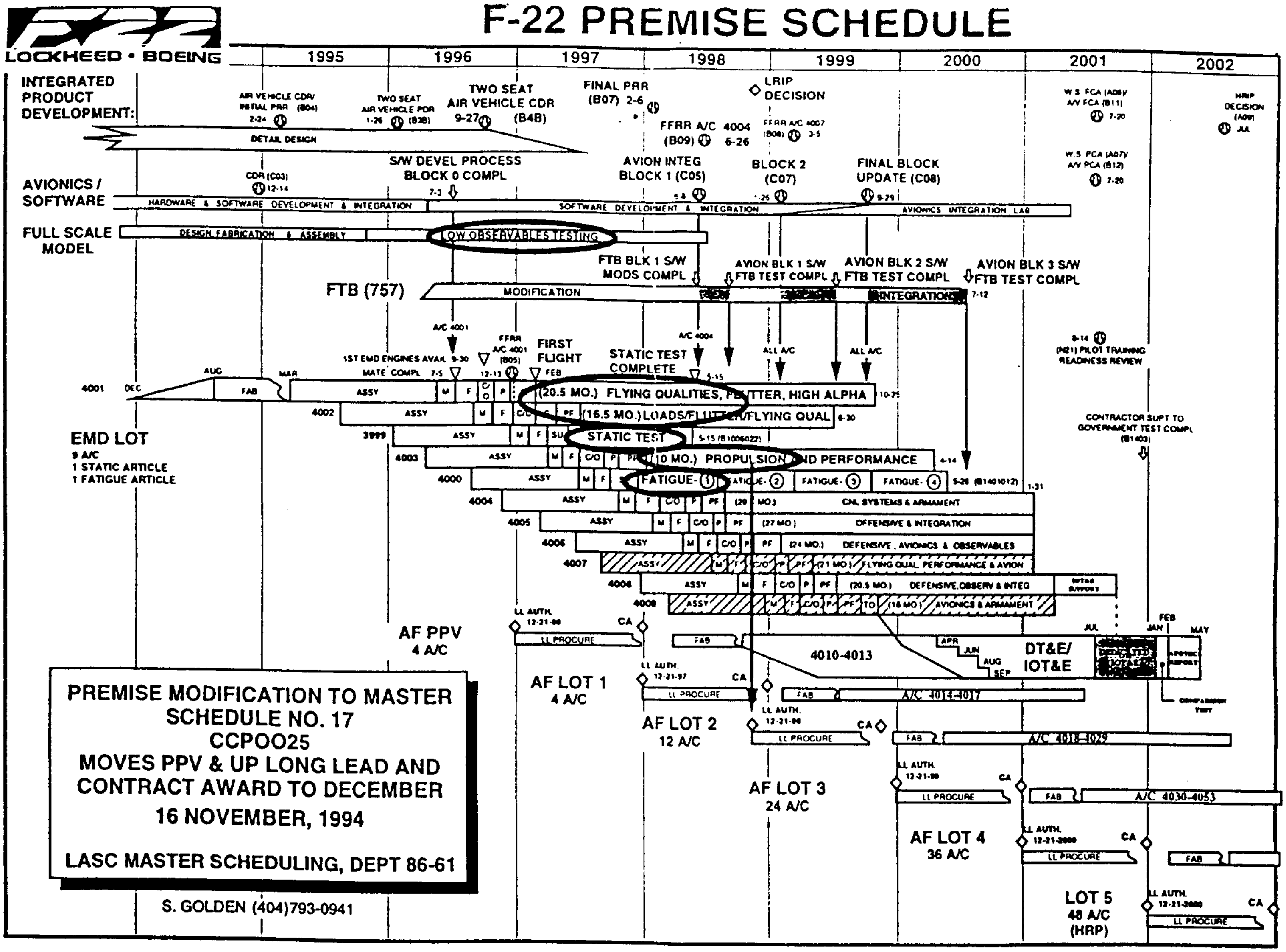
Vectored Thrust

Stealth

Situation Awareness

Integrated Avionics

The F-22 is the next generation air superiority fighter scheduled for introduction in the first decade of the 21st century. Its primary role is to counter emerging proliferating worldwide threats, and to maintain the overwhelming air superiority advantage needed by a downsized and reshaped U.S. military force. The F-22 is designed to penetrate enemy airspace and achieve a first-look, first-kill capability against multiple aircraft targets. The features that will permit the F-22 to achieve this advantage are: a low observable highly maneuverable airframe; extensive use of composites and low observable materials; advanced software-intensive integrated avionics providing improved situational awareness; and a new engine with a two-dimensional vectoring nozzle that is also capable of supersonic cruise without using afterburner.



The DSB schedule concurrency and risk assessment was based upon the above F-22 program schedule resulting from the Air Force FY1996 POM submission.

TASK FORCE APPROACH

- Define Concurrency
- Compare F-22 development schedule concurrency metrics to experiences of earlier tactical aircraft developments
- Conduct top-level critical technical and management areas review of F-22
- Identify key decision points for each critical technical area
- Assess F-22 degree of concurrency and risk

The Task Force addressed concurrency metrics first and then conducted the technical review.

DEFINITION AND COMPARISONS OF CONCURRENCY

- Definition*
  - Concurrency is the degree of overlap between the development and production processes of an acquisition program. Structuring the overlap is a management judgment balancing:
    - » Risk of proceeding
    - » Cost of delay, work force inefficiency, design obsolescence
- Comparison of F-22 concurrency with other relevant programs
  - IDA Study
  - RAND Study
  - Unpublished Source

* Source: DoD Report on Concurrency in Major Acquisition Programs; April 1990

Definition of Concurrency:
A number of definitions of concurrency are used by analysts, program managers, and program evaluators. For its report on "... Concurrency in Major Acquisition Programs,"[1] submitted to Congress in April 1990, the Department of Defense chose to define concurrency as follows:

> *"Concurrency" is the degree of overlap between the development and production processes of an acquisition program. Structuring this degree of overlap is a management judgment; a balancing of*
>
> - *the risk of proceeding with certain production and other activities weighted against the delay*
> - *known cost of delay caused by work force inefficiency*

The DSB Task Force used this definition in evaluating concurrency in the F-22 program. The definition both implicitly and explicitly states that concurrency in a major acquisition program calls for judgment. Concurrency is the degree of overlap, and implicitly degree is based on judgment. Explicitly the degree of overlap is a management judgment measured in terms of trade-offs and risks.

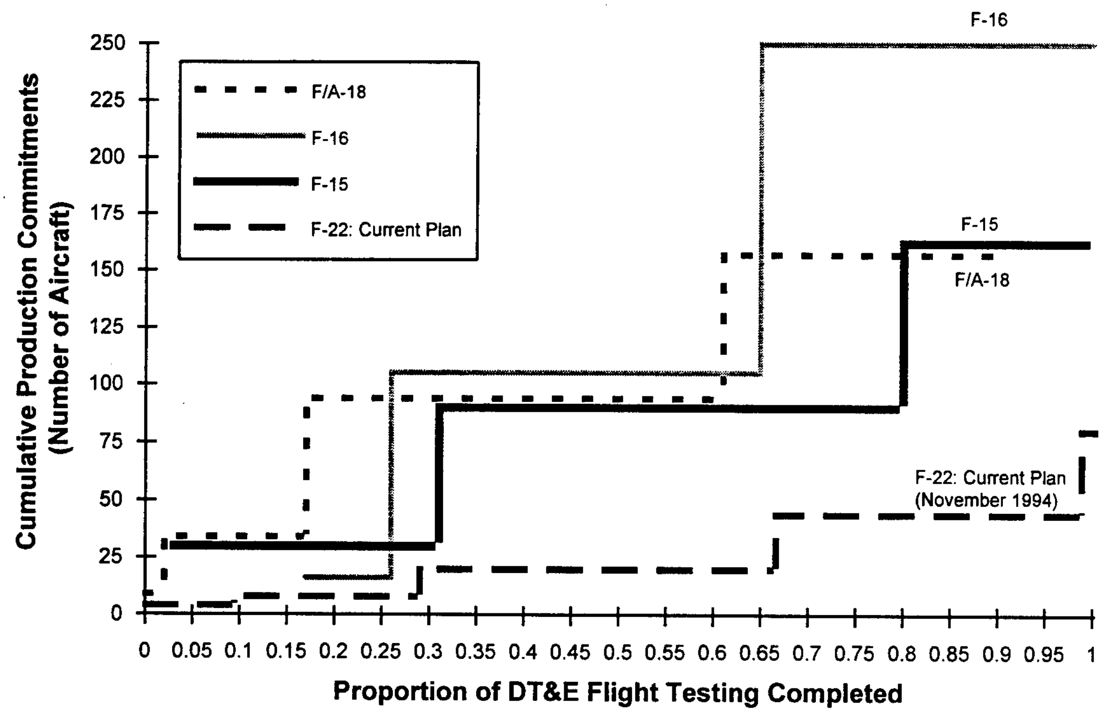
In addition, the Task Force was asked to address whether there were any areas of excessive concurrency in the F-22 program. The concept of excessive concurrency is a further judgment, understanding that some concurrency is prudent and that the risks of proceeding are often best evaluated in hindsight.

Concurrency Metrics:
A number of metrics could be used in comparing the F-22 development schedule concurrency to experiences with earlier tactical aircraft developments. The DSB Task Force drew on three sets of metrics—one used by IDA, one by RAND, and one by an unpublished source. Given the limited time available, the DSB did not create yet another metric or conduct an independent validation of the three sets of metrics. The existing metrics seem to be consistent in showing that the F-22 concurrency is comparable to that of other programs. The following paragraphs describe the metrics in more detail. In all cases, the Task Force used F-22 schedule data from the Lockheed premise modification to Master Schedule, No. 17, dated 16 November 1994.

---

1 The Under Secretary of Defense (Acquisition), *Report on Guidelines for Determining the Degree of Risk Appropriate for the Development of Major Defense Acquisition Systems, and Assessing the Degree of Risk Associated with Various Degrees of Concurrency; and Concurrency in Major Acquisition Programs*, Washington, D.C., April 1990.

CONCURRENCY BETWEEN FLIGHT TEST AND PRODUCTION
IDA Metric 1: Number of Production Aircraft Commitment During DT&E



Source of Historical Program Data: IDA Paper P-2105, February 1989, and IDA Document D-1214, December 1992.
F-22 Data from Lockheed Premise Modification to Master Schedule, No. 17, dated 16 November 1994.

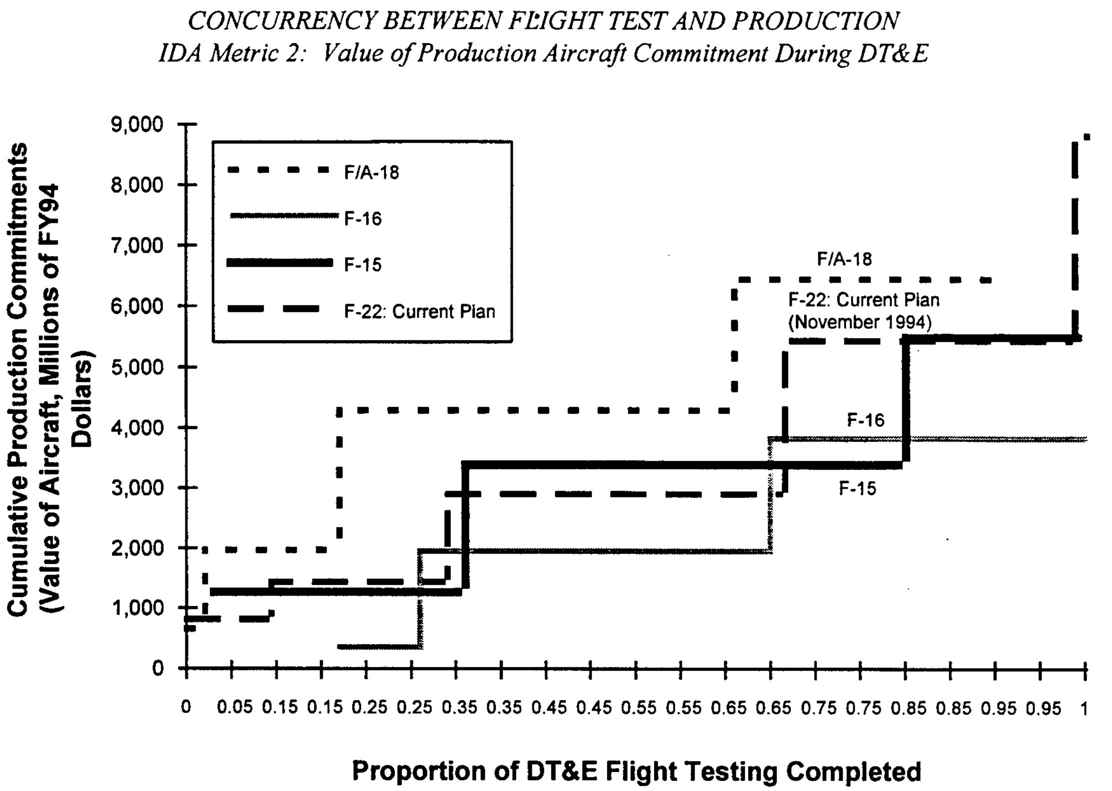
In its reports *Assessing Acquisition Schedules for Tactical Aircraft*[2] and *Schedule Risk Assessments for Tactical Aircraft,*[3] IDA looked at several concurrency metrics. For this DSB Task Force, IDA updated two measures of concurrency. The first, shown in the chart, compares the proportion of DT&E flight testing completed (on the x-axis) to the number of aircraft committed to production in terms of Long-Lead commitment (on the y-axis). (Data discussed later show that the duration of DT&E flight testing planned for the F-22 is significantly longer than for prior programs.)

When DT&E is complete in mid-2001, the 40 F-22 aircraft of Lots 1, 2, and 3, plus the Long-Lead items for another 36 aircraft (Lot 4), are scheduled to be on contract. This concurrency metric shows that fewer F-22 aircraft have been committed to production than was the case with the three most recent fighter aircraft programs.

---

2 Institute for Defense Analyses, Bruce R. Harmon, Lisa M. Ward, Paul R. Palmer, *Assessing Acquisition Schedules for Tactical Aircraft*, IDA Paper P-2105, February 1989.

3 Institute for Defense Analyses, Bruce R. Harmon, J. Richard Nelson, Neang Om, Janet M. Sater, Alec W. Salerno, *Schedule Risk Assessments for Tactical Aircraft Programs*, IDA Document D-1214, December 1992.



Source of Historical Program Data: IDA Paper P-2105, February 1989.
F-22 Data from Lockheed Premise Modification to Master Schedule, No. 17, dated 16 November 1994.
Historical Financial Data from DoD Sources.
F-22 Financial Data from F-22 SPO.

Looking at a different metric, IDA compared the proportion of DT&E flight testing completed to the dollar value of aircraft committed. While the F-22 is more expensive per aircraft, it has a profile similar to the dollar commitments on the other programs. The last commitment of funding, the commitment that raises the F-22 value higher than those for the other three programs, comes very late in the flight test program. There is, as will be seen in the following discussion, a considerable amount of time during which the DoD can delay making this last commitment if flight testing has shown difficulties. Thus, from the perspective of these two IDA metrics, the F-22 compares favorably with the other programs in terms of the degree of overlap.

LENGTH OF KEY PERIODS FOR FIGHTER/ATTACK AIRCRAFT

First Flight		EMD to First Flight (Months)	Static Test Duration (Months)	Fatigue Test Duration (Months)	* DT&E/OT&E Flight Test Duration (Months)	EMD to LL Release for Lot #1 (Months)	First Flight to LL Release for Lot #1 (Months)	EMD to First Production Delivery (Months)
1972	F-15	31	8	15	44	34 (for 30 A/C)*	+3	59
1976	F-16A**	23	12	18	25	23 (for 16 A/C)*	+0	43
1978	F/A-18**	35	22	50	40	24 (for 9 A/C)*	-11	53
1981	AV-8B**	31	29	33	37	25 (for 12 A/C)*	-6	55
1997	F-22 (est)**	68	12	29	63	78 (for 4 A/C)*	+10	112

* Size of 1st Lot
** Also had prototype in program
Source of Historical Program Data: IDA Paper P-2105, February 1989.
F-22Data from Lockheed Premise Modification to Master Schedule, No. 17, dated 16 November 1994.

Continuing to use IDA data for historical programs, this chart displays the key milestones for the F-22 and four other fighter/attack aircraft. In particular, the chart shows the duration of various testing. Static and fatigue durations are slightly below average. However, flight testing is planned over a longer duration—twice the average—potentially giving time to correct problems. Time from EMD start to first production is also planned to be longer than average, again giving an opportunity to correct any problems encountered. Long-Lead release for Lot 1 is after first flight. Thus in these categories, the F-22 time lengths seem reasonable compared with those of other tactical aircraft programs, particularly in light of the small number of aircraft in Lot 1.

FLIGHT TEST DATA COMPARISONS

	Number A/C	Air Vehicle Test Hours	Avionics Test Hours	Armaments Test Hours	R&M	Total Flight Hours	Average Hours/Flight	Average Hours Per A/C Per Month
F-15 A/B	20*	1,664	819	372	-	2,856	0.94	10.9
F-16**	10	1,638	489	174	280	2,581	1.24	16.5
F/A-18	12	2,365	591	952	1,013	4,922	1.43	16.2
AV-8B**	5	1,037	478	523	-	2,038	1.05	13.9
F-22 **	9	2,426	2,765	-	-	5,191	1.8	23.3

* The higher number of test aircraft for the F-15 might be explained by the fact that there was no prototype.
** Also had prototype in program

* The higher number of test aircraft for the F-15 might be explained by the fact that there was no prototype.
** Also had prototype in program
Source of Historical Program Data: IDA Paper P-2105, February 1989.
F-22 Data from Lockheed Premise Modification to Master Schedule, No. 17, dated 16 November 1994.

Continuing to use IDA data, the Task Force examined flight test data. The above chart displays the scheduled F-22 flight test hours—which exceed those of the other programs. It should also be noted that the avionics test hours are planned to be from three to five times greater than avionics test hours for prior programs.

The planned average hours per flight and per aircraft are higher than those for other programs because of the high number of flight hours and the relatively small number of test aircraft (nine). The 1.8 hours per flight exceeds the 1.6 hours per flight average in the YF-22 test program because of a planned heavy use of in-flight refueling. The 23.3 hours per month is calculated on a basis equivalent to the historical programs—Lockheed plans approximately 25 hours per month. Given Lockheed's optimistic estimate of flight hours per month, a sensitivity analysis is in order. At 19 hours per month—20% of the flight test hours would be accomplished by the time Lot 2 Long-Lead items are procured, compared with 30% in the current plan. The F-22 program does have an accelerated maturation; the Program Office attributes this to Demonstration/ Validation (DEM/VAL) benefits as well as structural integrity program benefits.

RAND STUDY ON F-22 PRODUCTION DECISION
(1989-1991; Updated November 1994)

Issue:
- When should production commitments be authorized?

How much system maturity is enough?

Approach:
- Link decisions to development flight test results
- Distinguish between kinds of problems
  - Potential program killers
  - Troublesome but manageable
  - Routine

Examine database of prior programs

Whether the timeline, number of aircraft, and funding commitments are consistent with other fighter aircraft programs, the question remains: "How much testing is enough to reduce risk to an acceptable level before committing to production?" A RAND project memorandum,[4] updated in November 1994, discussed this issue. Quoting from the preface of this Report:

> *"The Congress has, over the past decade, issued increasingly strong mandates to the Department of Defense for more testing of new weapon systems before those systems are put into production and delivered to the operational forces. Such testing takes time, and the consequent delays in start of high-rate production are not cost free. Delays increase the direct cost of production, and delay delivery of the new system to the operating forces. The hypothesis of this study is that there must be some point in time where the likely costs of further delay exceed the likely benefits of further risk reduction through more testing. This report describes a conceptual model, and an associated analysis process, applied to the F-22 program to help answer the question of how much testing is "enough" to justify authorizing start of high rate production of that system."*

RAND attempted to develop an analytic approach for using test results to help establish the timing of a production go-ahead decision. They examined the type of problems found during the flight testing and placed problems into one of three categories:

- Type 1: Potential Program Killers - these seriously diminish mission capability and are very difficult and/or expensive and time consuming to correct.

- Type 2: Troublesome but Manageable Problems - these seriously diminish mission capability but can be corrected; however, they require time and/or funding beyond the original program scope.

- Type 3: Routine Problems - these can be corrected within the original program budget and schedule.

RAND's analysis focused on Type 1 and 2 problems—the problems that have an impact on cost and schedule.

4 Giles K. Smith, *Use of Flight Test Results in Support of F-22 Production Decision*, RAND Corporation, PM-329-AF, November 1994.

RAND STUDY ON F-22 PRODUCTION DECISION: RESULTS

Findings:
- When major problems occur, it is usually within first 10-20% of full scale system development test
- No instances where major problems were first revealed in later phases of development test program

Conclusion:

Unlikely that keying production decisions to completion of IOT&E testing would substantially reduce technical risk

Using a database of prior programs, RAND estimated ways to link production commitments to flight test results. The RAND report described the following analytic results:

- Type 1 problems are rare, and when they occur it is usually within the first 10-20% of full-scale system testing.

- There are no instances when serious (Type 2) problems were first revealed in the later phases of the development test program.

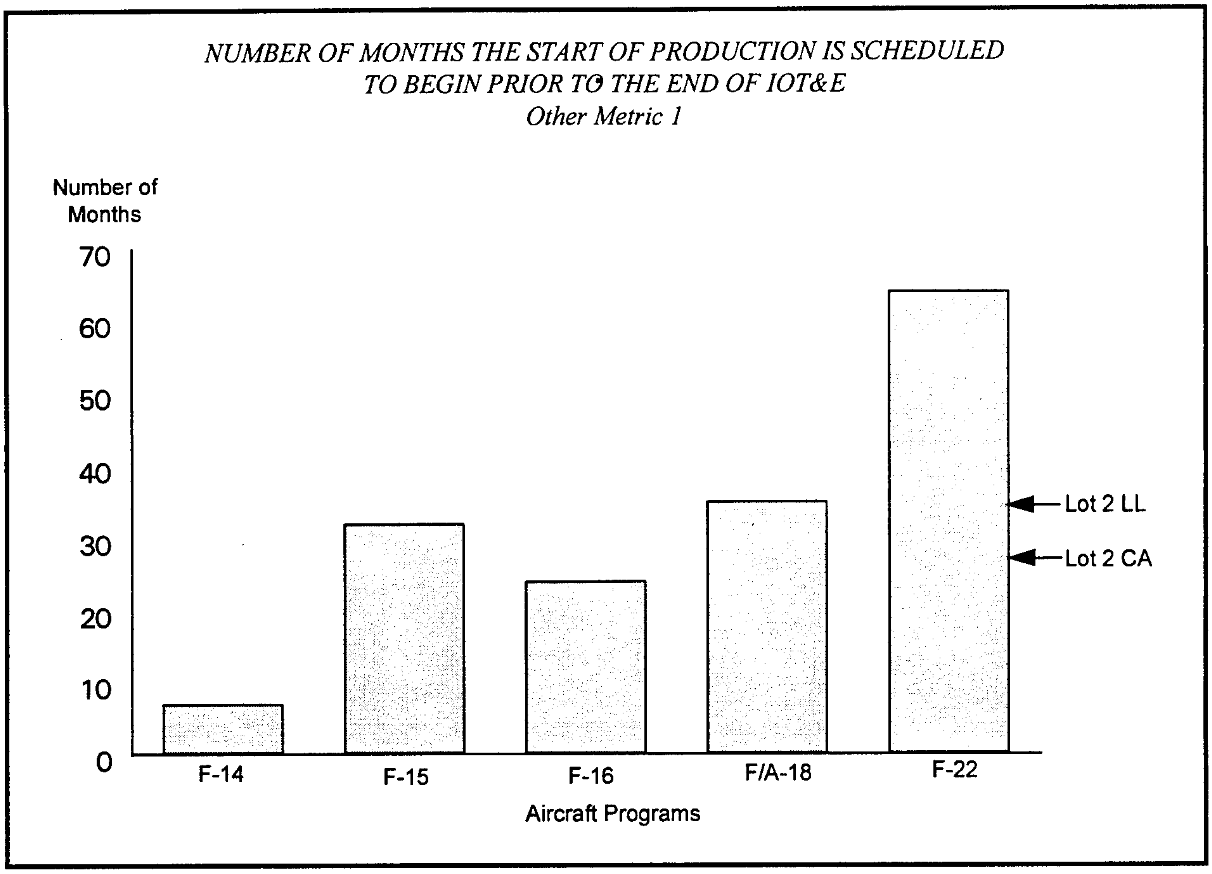
- It is unlikely that keying production decisions to completion of IOT&E testing would substantially reduce technical risk.

To put this in perspective, we looked at the current schedule of the F-22, and at 20% of full-scale system development testing. The Lockheed schedule calls for approximately 25 hours per month, with approximately 400 hours of flight testing scheduled by December 1997 (10 months using 1.5 aircraft), and approximately 1,400 hours by December 1998 (using 4 aircraft).

The 1,400 hours represent 27% of scheduled flight test hours. At that point, only the Long-Lead items for Lot 1 and 2 and Lot 1 Contract Award will have been committed. (To reach 20% of flight test hours, the F-22 would have to fly 1,040 hours.)

A large portion of testing on the F-22 is testing of the avionics. Flight testing of avionics begins in August 1998, and 20% of avionics flight testing is scheduled for completion by the first quarter of 1999 (Lockheed estimate). At that point, Long-Lead items for Lot 2 (12 aircraft) and Contract for Lot 1 should have been awarded.

Given the amount and duration of testing, it seems unlikely that keying production decisions to completion of dedicated IOT&E testing (February 2002) would substantially reduce technical risk. Further, it appears that keying production decisions to Lot 2 Long-Lead—or conservatively—Lot 2 Contract Award, should be sufficient to reduce risk.

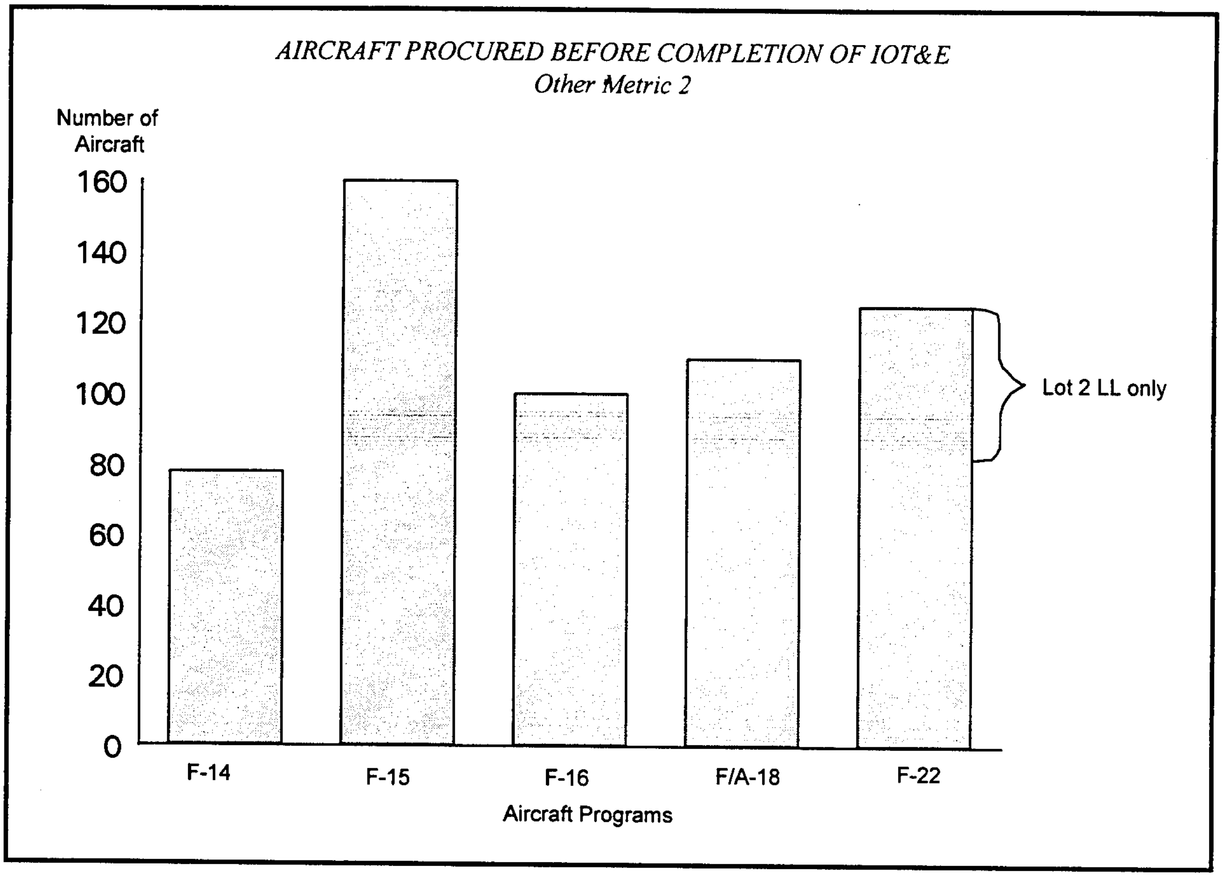


The IDA study focused on DT&E and the RAND study assessed the likelihood of problems occurring within DT&E and IOT&E. The DSB Task Force also had available for its review comparison data from an unpublished source that suggested two other possible concurrency metrics that focused on the end of dedicated IOT&E as the basis for production decisions. Dedicated IOT&E is currently scheduled for completion approximately 8 months later than completion of DT&E, or February 2002.

The unpublished data show the number of months from initial production to completion of dedicated IOT&E. The Task Force also indicated the Lot 2 milestones we believe critical to the program. Lot 2 was used as a benchmark for comparison because Lot 2 is the transition point from the 4-aircraft-per-year, to the 12-per-year production rate. Also, using the results from the RAND study, the Task Force believes that Lot 2 is a better milestone upon which to base production decisions. The two arrows on the F-22 bar show these two milestones: Long-Lead award for Lot 2 production and Contract Award for the Lot 2 buy. Using this benchmark, the chart shows that F-22 development compares favorably to that for historical, fighter aircraft in terms of when major commitment to production aircraft is made prior to the completion of the IOT&E test phase.

The chart also shows the stretchout of the F-22 program—there is a much longer delay (i.e., a longer test program) for the F-22 than for other programs. This delay represents, inter alia, risk reduction (more testing with more time to make improvements), funding shortfalls, and the trend toward longer procurement cycles (which acquisition streamlining initiatives are meant to reverse).

It is important to note that the historical aircraft development programs considered in this sample used Full-Scale Development (FSD) aircraft for IOT&E testing. The F-22 program will use Pre-Production Verification (PPV) aircraft to conduct IOT&E testing. Therefore, unlike the historical programs, the later F-22 production decisions will be based on IOT&E data accumulated on real production aircraft, not FSD aircraft.



The second concurrency metric suggested in the unpublished source is the comparison of the number of aircraft procured prior to the completion of IOT&E. As the chart shows, a total of 80 aircraft (the 4 PPV aircraft required for IOT&E, plus Lots 1-4) are to be contracted for before completion of IOT&E. In addition, the Long-Lead procurement for another 48 (Lot 5) aircraft is scheduled to take place in December 2001, two months before the scheduled end of dedicated IOT&E. Again, in comparison with the other programs, the degree of concurrency does not appear unreasonable.

SUMMARY FINDINGS REGARDING SCHEDULE CONCURRENCY METRICS

- F-22 Degree of Overlap
  - Consistent with other tactical aircraft programs
- Risk of Proceeding
  - Key date is Long-Lead for Lot 2, by that point 20% of flight test program is scheduled for completion
  - Cumulative cost for Lot 1 and 2 Long-Lead items plus Lot 1 (with support and training equipment) is approximately $1.3B
- Cost of Delay
  - SPO estimate of $8-10B additional cost over program for multi-year extension of LRIP
  - Contractors estimate of $2.3B if Lot 2 is reduced from 12 to 4 aircraft

In summary, we looked at three aspects of DoD's definition of concurrency.

- Degree of Overlap - The IDA metrics showed that the degree of overlap is consistent with other tactical aircraft programs.

- Risk of Proceeding - The technical risk of proceeding is evaluated using the RAND metric. The key date is Long-Lead for Lot 2; by that point, 20% of the flight test program is scheduled for completion. The cumulative cost for Lots 1 and 2 Long-Lead items plus Lot 1 aircraft (with support and training equipment) is approximately $1.3B. Using RAND's figure of the first 10%-20% of full-scale testing during which Type 1 problems are likely to occur, if at all, and the amount and duration of testing, it seems unlikely that keying production decisions to completion of dedicated IOT&E would substantially reduce technical risk.

- Cost of Delay - The cost of delay provided by the F-22 SPO and contractors Lockheed and Pratt and Whitney are shown above. The cost of delay provided by the F-22 SPO is $8B-$10B over the life of the program due to loss-of-learning, inflation, and further EMD stretch-out of testing and low rate production for 3 additional years of LRIP. In addition, Lockheed and Pratt and Whitney estimate that reducing Lot 2 from 12 to 4 aircraft would add $2.3B (assuming a 4% inflation rate) to the total cost of the current program. (RAND estimated this cost impact at $600M.)

TASK FORCE EMPHASIS

- Review of various concurrency metrics did not portray complete picture
- Task Force conducted a brief, but aggressive top-level critical technical and management review
  - Does program recognize key technical challenges?
  - Does a plan exist to monitor and manage these risk areas?
  - Is testing and demonstration early enough to assess program production readiness?
  - What is effect on combat capability if some or several goals are not achieved?
  - Can decisions regarding production lot quantity buy be deferred until later in EMD?
- Lot 2 (12A/C) Long-Lead and especially Contract Award considered critical milestones
- Key decision points identified for each critical-technical area
  - Airframe
  - Engine
  - Low Observables
  - Radar
  - Passive Surveillance and Electronic Warfare
  - Sensor Control/Sensor Fusion/Pilot Interface
  - Flight Control/Vehicle Management
  - Software

To assess the concurrency of the F-22 program in isolation does not give a complete picture of the potential technical or programmatic risks in the program. Therefore, the Task Force conducted a review of the technical and management status of the program in several key major system/subsystem areas. This was done in an effort to relate concurrency and technical risk.

The costs of concurrency risks within the F-22 program are directly related to the following four types of changes:

- Major structural/engine Long-Lead changes (most expensive)
- Fixed hardware Long-Lead changes (expensive)
- Changes to existing Line Replaceable Units (LRUs)
- Software changes only (may be expensive in terms of labor but no impact on production costs)

Lot 2 Long-Lead and Contract Award were chosen as the critical milestones to balance schedule and cost commitment, while ensuring the fielding of the system in a reasonable time.

AIRFRAME

Status:
- Weight excess of the order of 1,000 lbs. (relative to proposal)
- Combination of airframe and engine excess weight and excess specific fuel consumption (SFC) result in decrements in specification subsonic mission and ferry ranges and sustained load factors
- Extensive wind-tunnel and YF-22 flight tests provide confidence on engine-inlet compatibility and stability/control characteristics
- Extensive structural component and materials testing programs for risk reduction

Concerns:
- Weight control
- Extensive use of new materials and fabrication processes and new applications of materials
- Higher than previously experienced temperature/time durations for composites in supersonic flight legs
- 1st lifetime fatigue test scheduled for completion 3 months before Lot 1 contract authorization and Lot 2 Long-Lead procurement

Key Events:

• Static Test Complete	May 1998
• 1st Lifetime Fatigue Test	September 1998 Lot 2 Long-Lead Commit December 1998
• 2nd Lifetime Fatigue Test	March 1999 Lot 2 Contract Award November 1999

Status:
Current estimates put the airframe weight at the order of 1,000 pounds above the proposed weight, and estimates may not yet have stabilized. Special efforts are under way to control weight; as one example - a "Tiger Team" was convened by the Program Office, and it completed its report in December 1994.

Extensive structural and materials testing (and corresponding manufacturing development work) has been conducted to reduce risks in these areas.

Wind-tunnel and YF-22 prototype flight tests provide confidence on the generally satisfactory nature of engine-inlet compatibility and stability and control characteristics. Also validated to some degree were aerodynamic drag and other parameters along with estimating methods.

The current estimate of airframe and engine excess weights, together with the estimated excess engine specific fuel consumption, results in estimated decrements from specification values of subsonic mission and ferry ranges and sustained load factors.

Concerns:
There is a continuing concern over weight control and whether projected weight reductions through redesign will be achieved, and whether new estimates of excess weights of other parts and equipment will stabilize. The "Tiger Team" on weight control reviewed this problem and reported findings in December 1994.

There is extensive use of new materials and processes as well as new applications of established materials, including both composites and cocuring processes as well as welded metal castings and large forgings. While the materials and structural component testing for risk reduction have been comprehensive and all aspects of design and testing conform to Air Force Structural Integrity Program standards, only full-scale static and fatigue tests can provide a sufficient degree of confidence in the structural integrity of the

production configuration of the aircraft to warrant moving toward high-rate production. Completion of the static test and 1st lifetime of the fatigue test in September 1998 precedes by only 3 months the initiation of Lot 2 Long-Lead Procurement.

In terms of lifetime durability the higher average temperature-time durations for supersonic flight mission segments are more severe than in prior composite applications, although these temperatures are not in excess of allowable as determined in laboratory materials tests.

Key Events:
The key events are listed on the chart together with Lot 2 Long-Lead (LL) and Lot 2 Contract Award (CA) dates.

Conclusions:
The critical airframe areas in F-22 development are weight (including engine weight) and structural validation in static and fatigue tests. Aggressive weight control measures are being carried out but continued monitoring is warranted. A critical point in the structural integrity area is the completion of the first lifetime fatigue test; the schedule and progress in the structural test program should also be closely monitored.

ENGINES

Status:

- Excessive vibratory stress levels found in fan and high pressure turbine
- SFC too high - 15% for subsonic mission
- Fixes for stress problems require redesign of overstressed components and adjacent components (stress drivers)
- Fixes for excess SFC include several component efficiency improvements—major contributors are turbine and exhaust nozzle
- Estimated excess SFC of improved engine is 1.8%
- Estimated excess weight of improved engine is 120 pounds

Concerns:

- Large amount of "fixing" required
- Late in program to be working large performance deficiencies
- Unlikely to meet all performance/durability goals prior to first flight
- Program provides for fall back using interim engines in early flight test

Key Events:

• First Test of Flight Test Engine Core	July 1995
• First Test of Complete ISR* Configuration	October 1995
• Initiate Durability Test of Flight Test Engine	December 1995
• Begin Flight Test Engine Assembly	March 1996
• First Flight Test Engine Delivery	September 1996
• IFR** Milestone	December 1996
• FFR*** Milestone	December 1997
• ISR* Milestone, LRIP Decision	December 1998
• First PPV Lot Engine Delivery	March 1999

* Initial Service Release
** Initial Flight Release
*** Full Flight Release

Status:
The engine has excessive vibratory stress levels in the hollow-blade fan, and also in the high pressure turbine. Fixes have been found involving both the critical component designs and revisions in the configurations of adjacent components to change the vibratory forcing functions. There may also be durability issues in other hot section parts if temperatures are raised to meet performance goals.

The engine is also deficient in performance at a number of significant operating points. One of the most critical in operational terms is the subsonic cruise mission for which the SFC is 15% too high. The proposed fixes would result in an estimated subsonic SFC that is 1.8% above the current specification. These fixes involve design changes to improve component efficiencies and reduce flow losses at several locations in the engine. However, the largest projected improvements are in major redesigns of the turbines and the exhaust nozzle. These significant component redesigns will not be incorporated in an all-up test engine until the summer of 1995. The current estimate of engine weight incorporating the fixes is 120 pounds over the target weight originally specified.

Concerns:
The number and extent of the engine design changes needed to correct performance deficiencies is considerable. For fighter engines of this type, the components tend to be closely coupled as elements of the propulsion system. Design changes in one area may cause unanticipated effects in other areas of the engine.

It is highly challenging to be correcting significant shortfalls in performance at this time in the development cycle, particularly if EMD engines are to be available in time for installation in the first flight test aircraft in September 1996. Normally, at this stage of development, engineering and test efforts would be devoted primarily to solving problems of reliability and durability in the near-final configuration of the production engines.

Key Events:
As shown on chart.

Conclusions:
In view of the compressed time available for test validation and refinement of the modified engine (July 1995 availability of the core engine for test and October test availability of a complete engine including redesigned nozzle), it appears that it would be desirable to consider possible program alternatives in the event that unanticipated events preclude availability of currently planned redesigned engines in time for installation in the earliest flight test aircraft. It is understood that the SPO has a checkpoint for this purpose scheduled for mid-1995. Alternatives range from acceptance of an EMD engine with greater than 1.8% excess SFC based on trade-offs of operational effectiveness, cost, compatibility with force modernization phase, and other factors, to adopting an interim engine for some of the flight test aircraft and revising schedules. Schedule adjustments affecting concurrency may also be made at this decision point, if considered necessary.

LOW OBSERVABLES

Status:
- Many LO design and manufacturing challenges exist
  - Radar antenna, radome, nose integration
  - Gaps, cracks, seals, drains, etc.
- Program has plans to ensure that problems are identified early
  - Full scale RCS pole models (aircraft, inlet, canopy)
  - Production RCS imaging facility
  - Early LO flight test (EMD A/C #4)
- Infrared signature receiving proper emphasis based on F-22 capability and likelihood of encounter

Concerns:
- Program must maintain emphasis on testing full scale articles built with production components/processes

Key Events:

• Full-scale aircraft RCS pole model testing complete	June 1998
	Lot 2 LL Commit December 1998
• Early RCS LO flight tests complete	March 1999
	Lot 2 Contract Award November 1999

Conclusions:
- No unacceptable concurrency risk exists

Status:

During DEM/VAL the program constructed a full-scale radar cross section (RCS) pole model and demonstrated that the design could yield very impressive radar cross-section signatures. During EMD this design must be further refined with attention to integration of critical components as well as development of the manufacturing processes that are required to yield a low signature vehicle.

Many challenges exist. Two of the bigger ones are integration of the radar antenna and radome into the aircraft and attention to the details related to gaps/cracks/doors/seals and drain holes. These and other challenges are acknowledged by the program office and plans have been instituted to reduce risk.

The program will be conducting low observable testing throughout the EMD schedule. Full-scale RCS test fixtures, to include a full-scale aircraft model, will be used for these tests. The testing of full-scale hardware, and in many cases full-scale production hardware (antennas, leading edges, radome, canopy, etc.), will significantly reduce the development risk. Several programs that experienced problems either did not or could not test at full-scale. Full-scale RCS pole model testing will take place late 1995 through mid-1998.

The F-22 production line at Marietta, GA, will have a radar cross-section measurement system. This system will allow for each EMD and production aircraft to be measured (ground diagnostic RCS imaging). This will allow for an early evaluation of production manufacturing processes and their ability to achieve a low observable aircraft.

Low observable flight testing will commence with EMD A/C #4. These tests are critical as they will demonstrate the achieved radar cross-section of a flight vehicle built using the actual production line process. The initial results of these tests should be available in early 1998.

The infrared signature is secondary in importance to the RCS of the F-22 in view of the current threat definition. This area is receiving proper emphasis and a similar plan has been developed to refine the design and develop production processes.

Concerns:
It is critical that the program maintain and, where possible, increase emphasis on full-scale test articles that are built with production components and processes. Changes to the current low observable program schedule or a reduction in the reliance on production components or processes for testing will significantly increase the risk of concurrency.

Key Events:
In relation to the Lot 2 Long-Lead and Contract Award decisions, two low observable related significant events exists. Full-scale RCS pole model testing will be complete before the Lot 2 Long-Lead decision in December 1998 and early low observable flight testing will be complete before the Lot 2 Contract Award date of November 1999. Data from these events will allow the F-22 program, the Air Force, and OSD to evaluate the current status of the low observable design and manufacturing process. Data from these events can be used to support go-ahead decisions or alternative decisions to delay or reduce the Lot 2 quantity.

Conclusions:
No unacceptable concurrency risk exists in the F-22 low observable area. Reducing the Lot 2 production quantity at this time will not reduce the risk. Significant test data will be available prior to Lot 2 Long-Lead and Contract Award to more thoroughly evaluate program risks.

RADAR

Status:
- Components developed, and component performance said to be acceptable
- CIP throughput and memory demands within allocation
- Recently had "very successful" critical design review (CDR)

Concerns:
- Clutter rejection still to be demonstrated
  - Antenna/radome sidelobe performance said to be adequate
  - Vibrational effects on clutter rejection to be tested January 95
- RCS of antenna "a little high" - candidate fix to be tested February 95
- T/R modules - can contractors meet schedules of both F-22 and GBR?

Key Events:

• First complete radar	~April 1996
• Block I software tested in flying test bed (FTB)	~September 1998
• First radar flight in EMD A/C	~October 1998
	Lot 2 Long-Lead Commit December 1998
	Lot 2 Contract Award November 1999
• Block III software tested in FTB	~July 2000

Conclusion:
- Assuming near-term tests successful, radar hardware development proceeding well

Status:
The F-22 radar is a solid state electronically scanned multi-mode radar. Although quite different from any other current operational radar, it builds on a legacy of work on solid state transmit/receive (T/R) module development and the multi-mode nature of radars like that in the B-1B. The radar has also benefited from the long period since its initial design for the YF-22/YF-23, and the preceding Ultra Reliable Radar (URR) program. Even in the YF-22 program hardware, the issues were largely those of cost, especially of the T/R modules, and not of feasibility or producibility. The radar signal processing is done in the common integrated processor (CIP). It requires substantial amounts of throughput and memory, but this is said to be within CIP allocations. The real time control of the multiple modes is being worked in the mission software design and development. The reliability projection is so good that even a substantial shortfall would still result in a very maintainable system.

Concerns:
The Task Force has two performance concerns. The first performance concern arises from the requirement to detect low RCS targets against a clutter background. This requires very good sidelobe control of the antenna/radome combination. We were told, but did not verify, that the sidelobe performance was adequate. Such target detection in clutter also requires very stable reference oscillators. It is yet to be demonstrated that the requisite stability is achieved in the vibration environment of the aircraft. The second performance concern is that the contribution of the radar antenna to the aircraft RCS is above spec. This is a matter of precision in antenna impedance matching. The contractor has an approach to improving the performance that will be tested soon.

There is also a potential production concern that should be investigated by joint meetings between the relevant project offices. The F-22 radar and the Ballistic Missile Defense Organization (BMDO) Ground Based Radar (GBR) both make demands on one of the contractors, Texas Instruments, for T/R module production. Assurance should be obtained that both programs are comfortable that the potential impact of the other on their program schedule is negligible or acceptable.

Key Events:
The event schedule shows that the radar hardware will be delivered and installed prior to Long-Lead commitment to Lot 2 and will fly in an EMD aircraft before Lot 2 Contract Award. Thus, there appears to be little risk in the radar hardware concurrency.

Conclusions:
Assuming near-term tests will be successful, radar hardware development is proceeding well.

PASSIVE SURVEILLANCE AND ELECTRONIC WARFARE

Multiple (15-20) sources of passive surveillance designed to:
- Provide situational awareness
- Minimize active (radar) emissions
- Provide identification
- Cue defensive measures - weapons, electronic warfare (EW), flares

Status:
- CNI and EW CDR successfully completed
- Fusion algorithms prototyped, sample scenarios simulated, critical antennas prototyped

Concerns:
- Major advances in automated sensor management, multi-source integration and ESM system performance
  - Integrated architecture helps
  - Can back-off on performance of selected inputs
  - Must achieve integration
  - Potential antenna aperture problems are a concurrency concern
- Algorithms to deal with all the signal complexities, variabilities, and unexpected or conflicting events and parameters will be a significant challenge

Key Events:
- Proof of implementation progress will come during
  - Block 3 Avionics Integration - August-December 1999
  - Flying Test Bed & Aircraft Testing - October 1999-March 2000
- This is after Lot 2 Long-Lead and coincident with Lot 2 Contract Award

Conclusions:
- Very challenging area with the attendant risks
- Proceeding well and being carefully managed

The F-22 has many means of passively receiving situation awareness information from both its own sensors and external sources. The intent is to allow the pilot to see the threat situation while minimizing use of the active radar. These inputs will also help in identifying the threats and providing cues to the weapons, electronic warfare systems, and flares.

The passive surveillance system includes many stressing performance requirements. Most are well beyond anything previously accomplished on an airborne platform regardless of size. Particular areas of advance include automated sensor management, multi-source integration, electronic support measures (ESM) system performance, and target handling capabilities. These are major steps forward with the attendant risks.

Failure to achieve the current full specified performance in any one passive subsystem would not be fatal since so many potential information sources are involved. In the worst case, the active radar could be used more. However, that would increase the aircraft's observability against sophisticated threat systems.

To be successful, the integration of the multiple sources must be achieved. Presented individually, the data would clearly overload the pilot.

Status:
The current approach, progress, and plans appear sound. There are early efforts to identify, track, and address the key risks. Prototyping of the most stressing areas has begun. Fusion algorithms have been written and are being tested under different scenario loads. Testing and simulation is planned in dense emitter environments. Green Flag testing would stress the system considerably.

Concerns:
The primary risk relating to production concurrency appears to be from problems with the antenna apertures. If the system experiences field-of-view/obstruction problems, lacks sensitivity, or has co-channel interference, fixing the antennas could be very expensive - given the aircraft would already be in production, and the observability testing that would have to be redone.

There will likely be numerous software related problems found during integration and testing, particularly related to dealing with the variability of real emitters. These software problems, however, should not have an impact on the production concurrency issues being addressed here.

Key Events:
Key events in the integration of the passive surveillance and EW systems are in the Block 3 ground-based integration in August-December 1999 and then on the Flying Test Bed and aircraft early in 2000. These events occur after Long-Lead is released on Lot 2 and coincident with Contract Award for Lot 2.

Conclusions:
The requirements for this area are a major step forward in both ESM system performance and automated processing. Good progress is being made in the design, and the program is being carefully managed. This area must receive continuing close attention due to the potential risks and rather late scheduling of the key tests relative to Lot 2 production.

SENSOR CONTROL/SENSOR FUSION/PILOT INTERFACE

Motivation:
- Complex set of sensors in single seat aircraft
- Computer control necessary to manage workload

Status:
- Control and fusion algorithms being developed and tested against simulated threats/scenarios
- Cockpit simulator built; being used for interface evaluation

Concerns:
- Breaking new ground in pilot/sensor interface
- Software must work in all scenarios:
  - Accommodate changes in enemy tactics
  - Provide easy response to threat evolution
- Will require long evolutionary software development
- Pilot interface will also evolve - could necessitate hardware changes (probably not beyond LRU level)

Significant Events:
- First flight of complete avionics in EMD aircraft ~October 1999
  Lot 2 Contract Award ~November 1999
- First software (Block III) with significant levels of sensor control and fusion tested in FTB ~July 2000

Conclusion:
- An extended program in developing and updating mission software will be required; pilot interface hardware may need to be changed. This will probably not be known by Lot 2 Contract Award.

The F-22 incorporates a large number of sensors, many with an assortment of operating modes. It has a single part-time sensor operator (the pilot). These circumstances dictate that 1) the real time management and control of the sensors must be automated, 2) the data on each target from all relevant sensors must be correlated and its meaning extracted by a computer, 3) the reduced data must be presented to the pilot in a "user friendly" way, and 4) the required reaction of the pilot be facilitated by good engineering of his controls and switches. These tasks will be done on the F-22 by computer to a degree unprecedented, at least in tactical aircraft.

The result should be an impressive and very useful capability. Reaching that end will require mission software development process of 1) identifying threat signatures and tactics, both nominal and plausible variations from nominal; 2) crafting the procedures and algorithms to be used for situational awareness, threat assessment, and weapons control; and 3) generating and debugging the continuing software evolutions. This is well recognized throughout the F-22 organization. They hope and believe that the evolution can be confined to the software.

We caution that it seems likely that as large numbers of pilots learn the F-22, there may arise pressures to change displays and switch function/locations. Doing so may involve more than software changes, despite good efforts to provide system flexibility.

Conclusion:
The issues of control/fusion/interfaces are not thoroughly tested until the Block 3 software is available, at least to the FTB. The Block 3 FTB tests finish about 6 months after the Lot 2 Contract Award. It seems very likely that further changes in software will be required and quite possible that cockpit hardware changes may be desired. Hopefully, and most likely, these could be contained to the LRU level.

FLIGHT CONTROL/VEHICLE MANAGEMENT

Concerns:
- None - Risks are low

Status:
- Stability and Control flight tests occur early with few production commitments
  - Testing is 60% complete with 8 aircraft
  - 100% complete with 20 aircraft

Conclusions:
- Success can be reasonably expected
  - Design based on proven FBW technology
  - New features demonstrated on prototypes
    - » aerodynamics, supercruise, RCS
    - » pitch thrust vectoring
    - » high-alpha maneuvering
  - Important lessons learned from FY-22 mishap
    - » more rigorous, reliable EMD design process
    - » better integrated aero/thrust vectoring

Status:

The basic design approach uses proven fly-by-wire (FBW) concepts from previous programs. The major differences are a) somewhat unusual aerodynamics due to RCS and supersonic cruise, b) integrated pitch-axis thrust vectoring, and c) maneuvering at high angle-of-attack.

The new elements of the system have been previously demonstrated in DEM/VAL on the prototype YF-22 aircraft. For example, aerodynamic stability and control characteristics, which form the essential database behind the control system design, are accurately predicted for the prototype by computational models and wind-tunnel tests. Since the F-22's external planform is substantially similar to the prototype, we can expect the same high modeling fidelity in EMD. Thrust vectoring and high-alpha maneuvering were also demonstrated on the prototype, although vectoring was not as well integrated into the rest of the control system as it will be on the production aircraft.

The EMD flight control design approach effectively incorporates important lessons learned from a mishap in the DEM/VAL program. One of the prototype vehicles exhibited severe pitch oscillations on a max power go-around, resulting in a "gear-up landing" and subsequent fire. Post-accident investigations confirmed that this incident was not caused by hardware failures. Instead, the prototype's flight control algorithms made the closed-loop aircraft PIO-prone (PIO stands for pilot-induced oscillations—a misnomer, since the aircraft is really at fault, not the pilot). Transient changes in thrust vectoring and gear settings on the specific go-around triggered the oscillation event. It turns out that several analytical control metrics exist which predict PIO-tendencies, and better control algorithms can readily be designed. The modified EMD design approach makes good use of these metrics and is, in general, a much more rigorous and reliable process for designing the flight control system. It also includes an elegant integration of the aerodynamic control and thrust vectoring features of the aircraft, which is much improved over the prototype.

Conclusions:

The flight control/vehicle management system appears to be in good shape.

SOFTWARE

Observations:
- Common Development Process/Tools
- Good Digital Architectural Design
- Available Core Hardware and Software
- Four Major Block Releases of Software
- Extensive Ground and Flight Test
- Early Block Releases Address Greatest Production Risks
- AFOTEC Operational Assessments Concurrent With Development Flight Test
- Software Block Schedules Must Be Met To Achieve Production Schedule

Common Development Process/Tools:
A common software development process and software engineering environment have been imposed for use in the F-22 program. Contractors have accepted this uniform approach and have made provisions for the corresponding requisite training to ensure consistency in implementation.

The software development process, which represents a tailored DoD-STD-2167A approach to software development, consists of methods that were defined by the contractor Integrated Product Team (IPT). Compliance to this process is monitored by a robust set of software metrics, as well as software tools that automate some aspects of the process.

The use of the common Software Engineering Environment (SEE) enhances team communication and facilitates system integration. The environment is comprised of both commercial off-the-shelf (COTS) software products as well as team developed software tools. The SEE has been baselined and modifications to its various components are subject to configuration control. In addition, the use of a common interface database ensures interface consistency throughout the development process.

Good Digital Architectural Design:
An open systems approach has been applied to the design of the digital architecture. The hardware architecture has been designed in a modular fashion that enables the addition of processing components to the backplane without requiring any software modifications.

Similarly, the modular approach to the design of the software enables the inclusion of additional functionality without adverse impact to the current design/capability.

Available Core Hardware and Software:
Core hardware and software (including the common operating system and SEE tools) are now available for use, providing the basis for development of the application specific aspects of the program.

Four Major Block Releases of Software:
An evolutionary approach to software development is implemented via four block releases (0-3) each of which provides greater functionality by building on the previous release.

- Block 0 provides the flight control software, full IRS functionality, all operating systems, stores management, and basic CNI functions.

- Block 1 provides mission data edit and event dates, single sensor control and display, initial radar functionality, additional CNI capability, and fusion.

- Block 2 provides additional radar and CNI capability and initial functionality in EW and weapon stores management.

- Block 3 represents the extension and integration of functions provided in the previous blocks, in addition to an embedded training capability.

Extensive Ground and Flight Test:
The F-22 program provides ample opportunity for detecting potential software problems through an extensive incremental process that includes both ground and flight test. The stages of this process are:

- *Software Testing.* This stage includes all aspects of testing during the actual software development process (i.e., code and unit test, integration test, quality assurance test, IV&V, etc.).
- *Sensor Stand Alone Test.* This stage enables testing of the software with actual sensor input.
- *Avionics Integration Lab.* This stage facilitates integration testing of the software within the full avionics system, supported by simulation as required.
- *Flying Test Bed.* This stage enables testing of the software in a "near" real-time environment, facilitated by exercising and fusing actual sensor data.
- *Flight Test Aircraft.* This stage provides an operational test environment in which to fully exercise within as realistic an environment as possible the full software functionality, including error detection, and system bounds.

Early Block Releases Address Greatest Production Risks:
The costs of concurrency risks within the F-22 program are directly related to the following four types of changes:

- Major structural/engine Long-Lead changes (most expensive)
- Fixed hardware/database Long-Lead changes (expensive)
- Changes to existing LRUs
  - New LRUs must be developed, or existing LRUs modified
  - More existing LRUs must be built for added processing power (less expensive impacts on production)
- Software changes only (may be expensive in terms of labor but no impact on production costs)

With regard to F-22 software, testing of Block 0 will address the major structural issues (most expensive types of changes.) Blocks 1-3 will address the remaining categories of potential changes. Block 3.1, which will address software-specific issues only, is unlikely to surface any changes other than those that impact the software directly. Accordingly, the greatest concurrency risks should be identified by the early block releases. The last block release should have little, if any, impact on production aircraft.

AFOTEC Operational Assessments Concurrent With Development Flight Test:
During the software development and testing process, the Air Force Operational Test and Evaluation Center (AFOTEC) will be conducting operational assessments. The results of these assessments should identify potential IOT&E problems long before the official IOT&E occurs. In fact, AFOTEC input will be taken into consideration prior to the LRIP decision currently scheduled for December 1998.

Software Block Schedules Must Be Met to Achieve Production Schedule:
A basic assumption used in the formulation of the software observations is that the schedules currently planned for software development must be met, and that the functionality to be provided within each of the Blocks as currently defined must be retained. If a slip occurs within the software development schedule, the resultant slip may adversely impact production.

SOFTWARE (Continued)

Status:
- Requirements reasonably solid
- CDR currently underway
- Contractors moving into code/unit test stage

Concerns:
- Maintaining the software schedule

Key Events:
- Release of Block 3 software to flight test (29 September 1999) should precede the Contract Award for Lot 2 production

Status:
The mission software requirements including interface requirements are reasonably solid having used the automated requirements and top level design methodology (ADARTS). All contractors are using these common tools. Detailed design is well underway and at the time of this writing (7 December 1994) the vehicle Critical Design Review is in progress. The contractors have begun to move into the code and unit test phase of the mission software.

Concerns:
The major software concern is that of maintaining the block release schedule with the functionality planned. With over 30 contractors contributing to the 1.4 million source lines of code, it is important to have enough of the proper resources applied to ensure that the delivery schedule can be met without compromising the discipline of a good development process.

Key Events:
A key milestone event is the release of Block 3 software to flight test (29 September 1999). It is important that this event precede the Lot 2 production Contract Award scheduled for late 1999. A review (discussed later) must validate the observation that Block 3 flight test will have minimal impact on the Lot 2 production configuration.

SOFTWARE (Concluded)

Conclusions:

- The software block releases are such that the earlier releases test those functions with the highest cost risk to production changes
- A review of Block 3 functionality reveals a low likelihood of any significant cost impact on production aircraft that would not have been identified by earlier ground or flight test or by operational assessments by AFOTEC
- The software development among all the contractors must be carefully planned and replanned to keep critical paths through the development on schedule
- A review of the following is prudent prior to Lot 2 Contract Award for Production to assess the concurrency risk:
  - Block 1 & 2 flight test results
  - Block 3 Avionics Integrated Laboratory results
  - AFOTEC operational assessments/plans

Block 0 software release in mid-1996 essentially permits the flight test program to validate major structural, aerodynamic, and safety objections early in the flight test program. The results along with static test and fatigue test results should feed into the LRIP decision in late 1998 that influences the Lot 2 aircraft Long-Lead procurement decision.

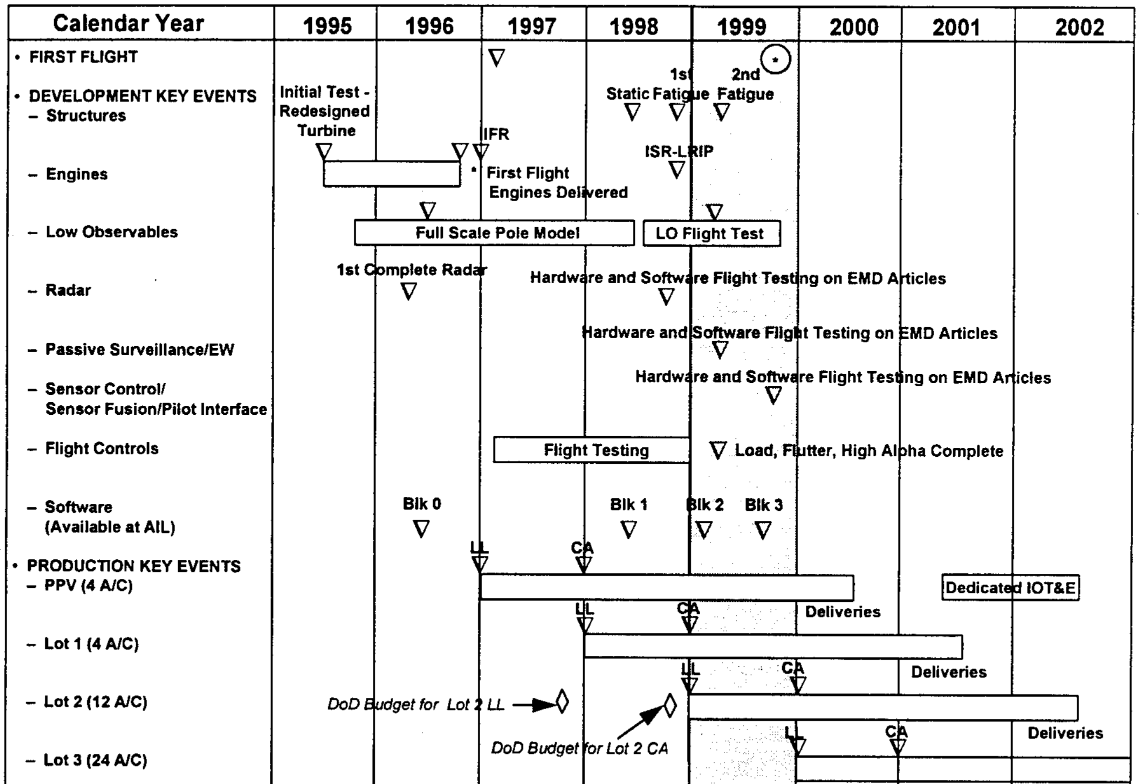
The flight test of Block 1 and 2 software functionality should exercise the avionics hardware to demonstrate most of the individual functions the hardware is to perform. Any major hardware changes should become evident during this phase.

Block 3 functionality essentially integrates the functionality that has been previously tested. Avionics Integrated Laboratory (AIL) testing and earlier testing should have identified any major hardware changes. The flight test of Block 3 would most likely point to software changes, or the need for more processing capability. Changes of this sort would have only very minor cost impacts on the production aircraft. It is important to know that the testing has been in the right "ball park" concerning OT&E. One can rely on concurrent "operational assessments" being conducted by AFOTEC to make this latter assessment.

An activity net of all the key software development tasks among all the contractors with their detailed planning would be useful in determining the critical path through all the contractor activities that determine overall schedule. Since the process is dynamic, the critical paths must be reassessed frequently with the objective of identifying key problems, finding resources across the IPT to resolve those problems, and containing critical path extensions without compromising a good engineering process. A central design and implementation focus on the software progress would be very useful.

A key review should be held prior to the Lot 2 Production Contract Award after reviewing Block 1 and 2 flight test results, Block 3 ground test results, and the AFOTEC operational assessments and plans. This review can verify the observation that there are only minor production cost impacts in proceeding with Lot 2, if that is the case. If not, then a more optimal Lot 2 buy could be made. The review point is shown during late 1999 by the asterisk on the top line of the present schedule chart on Page 3 and the key events chart on the next page.

F-22 ACQUISITION KEY EVENTS



IFR - Initial Flight Release-Engine; ISR - Initial Service Release-Engine; LRIP - Low Rate Initial Production; AIL - Avionics Integration Laboratory - Software

The F-22 Acquisition Key Events as determined by the Task Force are presented on this chart. First flight, development key events, and production key events are displayed. The critical milestones for Lot 2 Long-Lead and Lot 2 Contract Award span the year 1999, which is shown shaded in the chart. For each technical area, there are several key test events prior to Lot 2 Long-Lead and Contract Award for production that can be used to measure progress.

GENERAL OBSERVATIONS:

- Short time/limited effort by Task Force: 6 days total, 2 at contractors
- Overall program appears well structured and managed
- Top government and contractor people impressive
- The "spec" system provides major advances in capability across the board
  - Hence, less than spec performance in certain areas will still result in very capable system
  - As program progresses, this permits performance to be traded for cost/schedule

The Task Force had a limited amount of time to carry out its work. A total of six (6) days of meetings were held; two in Washington, D.C., receiving briefings on the program and relevant studies; two at the contractor's plant reviewing the major subsystems in detail; and two in Washington, D.C., reviewing findings and drawing conclusions. There was also much additional data gathering and consultation by individuals.

In spite of this limited effort, the Task Force believes it gained sufficient understanding of the program to be confident its findings are sound.

The overall program appears well structured, sound, and well managed. We were favorably impressed by the knowledge and objectivity of both the government and contractor staff with whom we interacted.

The "spec" F-22 system provides significant advances in every important aspect of a tactical aircraft. "Less-than spec" performance, if encountered in certain areas, will still result in a system that will be a large step ahead of current U.S. and likely opponent capabilities for a long time, and will thus continue the "overwhelming superiority" of U.S. forces in this area.

As the program progresses, any shortfalls in sub-area performance can be reviewed and appropriate trade-offs made with cost and schedule.

PLANS/OPTIONS TO MITIGATE RISKS

- No completely independent alternative approaches for big ticket items (e.g., engine/radar) exist nor are any recommended
- Alternate approaches in parts/sub areas are being pursued in some cases and more are doable within the program plan
- The general approach should be to handle problems by accepting some reduced performance, slip in schedule, or both, depending on risk/cost trade-offs

The Task Force was tasked to address the issue of viable plans/options available to mitigate high risk areas.

We found that there were no alternative completely independent approaches being pursued for the major subsystems (such as the engine or the radar) and we concluded that such alternate approaches were neither practical nor needed.

There are, of course, alternate approaches being pursued or reviewed at the part/component level (e.g., turbine blades), and others (e.g., LO, CNI antennas) can be accommodated within the program's plan and schedule.

We concluded that the best approach to handling problems that do arise is to seriously consider accepting some reduced F-22 performance, slip in the schedule, or some combination of both. As has been noted elsewhere in this report, F-22 performance in many areas, if it fell short of that specified, would still represent a major increase in military capability. Rigid adherence to the current specifications and goals would generally be unproductive and very costly.

SUMMARY CONCLUSIONS

- The program is very ambitious technically
- For each risk area there are significant achievements that should be demonstrated before release of funding for Lot 2 (12 aircraft) Contract Award
- The engine and the passive surveillance avionics are the highest risk areas
- In the event of inadequate progress, the program can be slipped by staying at the 4 aircraft per year rate
- Stretching the program in this way may reduce risk but can create cost, manpower, and obsolescence problems
- There is no risk-concurrency reason to introduce such a stretch at this time

With its many "first time" features for a fighter (super cruise, vectored thrust, stealth, passive location system, integrated avionics), the F-22 is one of the most challenging developments undertaken in recent times. The overall program, starting with the prototype in the Demonstration/Validation Phase and related R&D efforts, has been structured to address all these areas in an orderly, appropriate way and much has been accomplished.

From the standpoint of risk/concurrency, the critical point in the program is the ramp-up in the production program from 4 aircraft to 12 aircraft per year (Lot 2).

The Task Force identified for each risk area specific significant events whose accomplishment should take place before release of Contract Award (and to a lesser degree Long-Lead) funding for Lot 2, the 12 aircraft buy.

It should be noted that, at this time, the engine and the Passive Surveillance avionics subsystem have the greatest number of uncertainties. Consequently, if there are changes in the program plan, emphasis on these two areas should receive special attention and continued support.

If there are significant delays in accomplishment of these key events or if the performance levels achieved are unacceptable, the program could be adjusted by staying at the 4 aircraft per year production rate for an additional year.

It is noted that, while stretching a program may reduce risk, if stretching is not necessary it can result in increased total costs, possible loss of key manpower and suppliers, and earlier technical/operational obsolescence.

After careful review of the program plans and accomplishments, the Task Force concluded that there are appropriate future milestones on which to judge readiness for production ramp-up. Thus, there is no reason based upon risk/concurrency to introduce a schedule stretch at this time.

APPENDIX A

TASK FORCE MEMBERS

MEMBERSHIP

Chairman
Charles A. Fowler

Members
John Allen
Alexander Flax
Joan Habermann
Robert Nesbit
Philip Soucy
Richard Sylvester

Special Advisor
Gunter Stein

DSB Liaison
L/Col Keith Larson

Co-Executive Secretary
Dean Gissendanner
Col George DeFilippi

Government Advisors
Don Dix, DDR&E
Col Chuck Brammeier, OT&E
Virginia Castor, DDR&E
Roy Hempley, PA&E
Frank Traceski, OASD(ES)
Jim Bachand, OASD(ES)

Support Working Group—Institute for Defense Analyses
J. Richard Nelson
John N. Donis
Bruce R. Harmon
Joseph W. Stahl
Melanie G. Mutton

APPENDIX B

TERMS OF REFERENCE

THE UNDER SECRETARY OF DEFENSE

3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

ACQUISITION AND
TECHNOLOGY

November 1, 1994

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Terms of Reference -- Defense Science Board Task Force on Concurrency and Risk of the F-22 Program

You are requested to establish a Defense Science Board Task Force to assess the degree of concurrency and risk in the F-22 program in accordance with SASC Report 163-282, dated June 14, 1994. The scope of your assessment should be based on the most recent rephasing of the F-22 program. Work should begin as soon as possible with the Task Force providing an interim report by 15 December 1994 and a final report by 31 March 1995.

The Task Force should address the following questions:

Are there any areas in the F-22 program of excessive concurrency? What is the risk in each area?

For any areas of identifiable high risk, are viable plans/options available that would mitigate the risk?

What conclusions regarding F-22 concurrency and risk can be drawn by comparisons to existing data (e.g., an ongoing IDA study) on previous fighter/combat aircraft programs?

The Director, Tactical Warfare Programs will sponsor the Task Force, providing funding and other support as necessary. Mr. Charles Fowler will serve as Chairman of the Task Force. Mr. Dean Gissendanner and Colonel George DeFilippi of the Office of the Director, Tactical Warfare Programs, will serve as the Task Force Co-Executive Secretaries. Lt Col Keith M. Larson, USAF, will be the Defense Science Board Secretariat Representative.

It is not anticipated that the work assigned to this Task Force will cause any member to be placed in the position of acting as a procurement official.

Paul G. Kaminski

Paul G. Kaminski

APPENDIX C

TASK FORCE SCHEDULE

TASK FORCE SCHEDULE

3 November 1994 - Washington, D.C.
- Program Office Program Overview
- IDA Study on Concurrency

4 November 1994 - Washington, D.C.
- Program Office Detailed Briefings
  - Airframes, Engines, Avionics

16 November 1994 - Marietta, GA
- Lockheed Overview Briefings
- Hangar Tour & Demos

17 November 1994 - Marietta, GA
- Lockheed Detailed Briefings
- Individual Sessions

6 December 1994 - Washington, D.C.
- Task Force Discussions

7 December 1994 - Washington, D.C.
- Task Force Discussions
- Brief Findings to Director Strategic and Tactical Systems